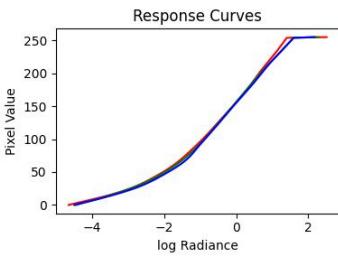
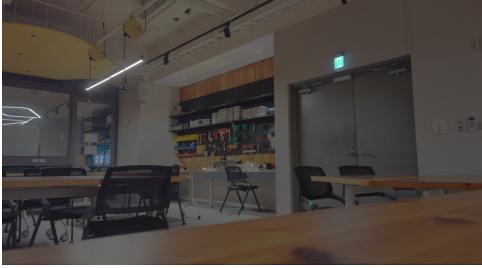
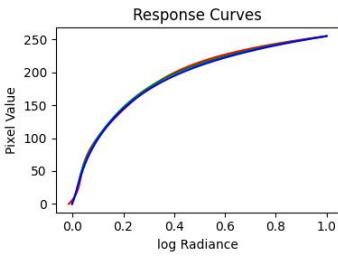
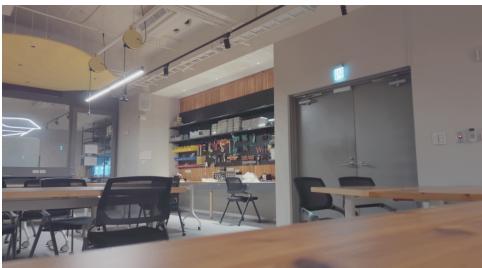
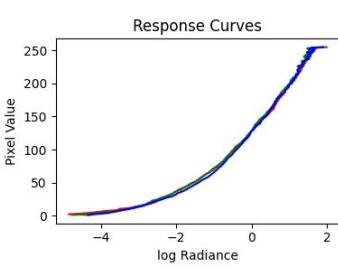


VFX Homework 1 Report

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1. Comparing Different Results

1.1 Comparison of HDR Methods using Fast Bilateral Filtering

HDR Method	Results	Response Curve	Comments
Paul Debevec			Scales better to show bigger range for HDR image.
Mitsunaga Nayar			Small color segment mistakes (3DP on the left), which is less robust
Robertson			Less smooth curve, but is more robust to the points picked.

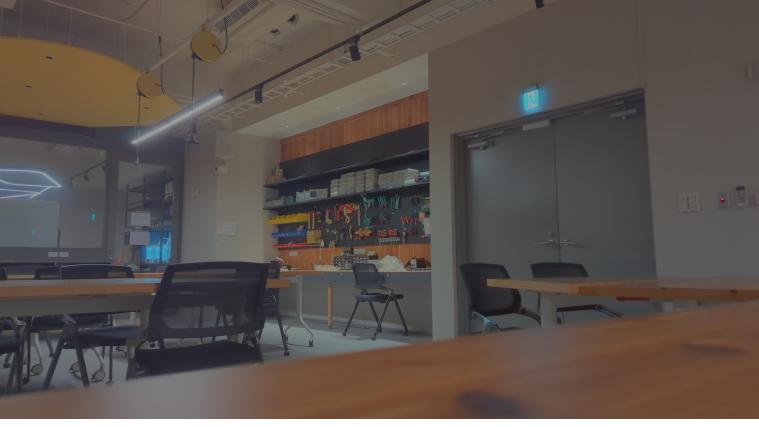
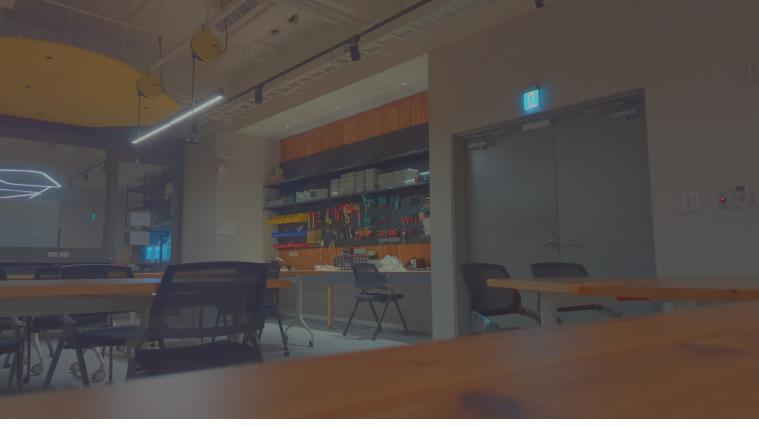
Analysis:

Personally, I like Paul Debevec's results best, although it depends a bit on the points chosen (it is not as robust as Robertson's), it results in a better contrast for darker and lighter spaces, which really demonstrates the value of HDR images.

The response curve for Mitsunaga & Nayar is different because it is not plotted on the log space, but instead it is original, since the results are in the range of 0 ~ 1. We are not sure of its real scale so logarithmic results may differ a lot.

The time needed for the algorithms differ by the number of points chosen, which I already tuned to show the results, but overall Debevec's method needs the least amount of time, while Mitsunaga & Nayar's method needs the most time.

1.2 Comparison of Tone Mapping Methods using Paul Debevec HDR

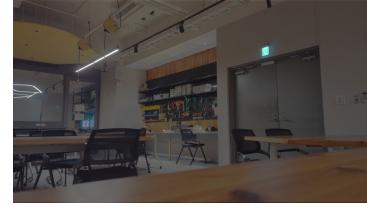
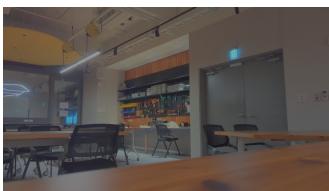
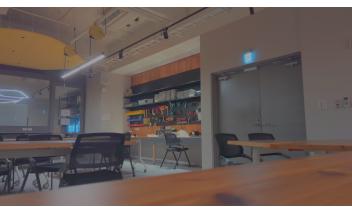
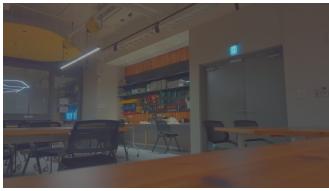
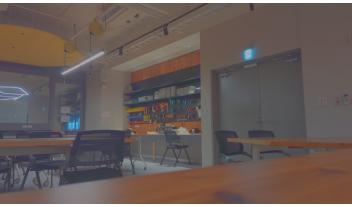
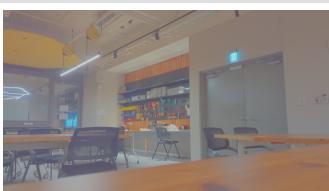
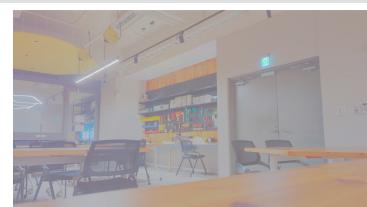
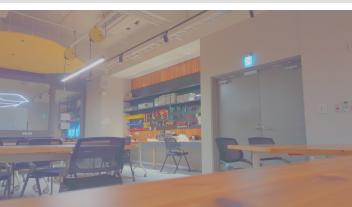
Tone Mapping Method	Result	Comments
Fast Bilateral Filtering		The contrast is stronger, which means that black is blacker and white is whiter. Also preserves edges better. (looks better)
Drago		Contrast is not as sharper as Fast Bilateral, but shows the whole image clearly (more real)
Mantiuk		slightly blurry with less luminance

Tone Mapping Method	Result	Comments
Reinhard		slightly blurry with more luminance

Analysis:

Overall, I like fast bilateral filtering (Durand's method best). It preserves the contrast of the images while also showing clearer edges of each part. It captures the light more naturally, too. However, fast bilateral filtering needs the most time and may differ by how large the gap is between the brightest and the darkest point.

1.3 Comprehensive Comparison of All Methods

Methods	Paul Debevec	Mitsunaga Nayar	Robertson
Fast Bilateral			
Drago			
Mantiuk			
Reinhard			

2. Implementations

2.0 Summary of Implemented Algorithms

- MTB (Median Threshold Bitmap) Algorithm
- Paul Debevec HDR Method
- Mitsunaga & Nayar HDR Method
- Robertson HDR Method
- Fast Bilateral Filtering Tonemapping Algorithm

2.1 MTB (Median Threshold Bitmap) Algorithm

Implementation Steps:

1. **Image Conversion:** Convert each image to grayscale
2. **Median Calculation:** Compute the median value of each grayscale image to align all images with the reference image
3. **Bitmap Creation:** Create a binary bitmap where pixels above median are 1, others 0
4. **Exclusion Mask:** Generate exclusion masks to ignore pixels too close to the median
5. **Pyramid Search:** Implement a hierarchical search to find the best alignment offset
 - Start with a coarse search at low resolution
 - Refine the search at higher resolutions
6. **Subpixel Alignment:** Apply the computed offset to align all images with the reference image
 - Construct a system of equations based on pixel values and exposures

2.2 HDR Algorithms

Paul Debevec Method

1. `sample_pixels (Select Pixels)`

- **Sample:** Randomly choose a fixed number (`num_samples`) of pixel locations (`y, x`) from the image dimensions.

2. `recover_response_curve (Estimate CRF using Least Squares)`

- **Goal:** Find the inverse Camera Response Function g (mapping pixel value Z to log exposure $\ln(E)$) and the log irradiance $\ln(E_i)$ for each sampled pixel i .
- **Linear System Setup (per channel):**
 - Create a large, sparse matrix `A` and a vector `b`.
 - **Data Fitting Equations:** For each sampled pixel i and each image j :
 - Add an equation: $g(Z_{ij}) - \ln(E_i) = \ln(\Delta t_j)$.
 - Apply a weight w (from `weight_function`) to this equation.

- **Smoothness Equations:** For each pixel value z (except ends):
 - Add an equation: $g(z - 1) - 2g(z) + g(z + 1) = 0$.
 - Multiply this equation by a smoothness factor `lambda_smooth` and weight w .
- **Constraint:** Add an equation to fix the curve's scale, e.g., $g(128) = 0$.
- **Solve:** Use linear least squares (`np.linalg.lstsq`) to solve the system $Ax = b$ for the unknowns x (which contains all $g(z)$ values and all $\ln(E_i)$ values).
- **Extract CRF:** The first 256 values of the solution vector x represent the recovered g (the log response curve).

3. `create_hdr_image` (Merge LDRs into HDR)

- **Weighted Average in Log Domain (per pixel):**
 - For each input image:
 - Get the pixel value Z .
 - Use the estimated CRF g to get the log radiance value: $\log_{rad} = g(Z)$.
 - Subtract the known log exposure time: $\log_{rad} = g(Z) - \ln(\Delta t)$.
 - Calculate a weight w (using `weight_function`).
 - Compute the final log HDR pixel value as the weighted average of these `log_rad` values from all images.
- **Convert to Linear:** Apply `np.exp()` to the resulting log HDR image to get the final linear HDR radiance map.

Mitsunaga Nayar Method

1. `sample_pixels` (Select Representative Pixels)

- **Filter:** Keep only pixel locations (y, x) that are non-zero in all images and have strictly increasing brightness values across the image sequence.

2. `recover_response_curve` (Estimate CRF & Exposure Ratios)

- **Model CRF:** Assume the Camera Response Function g (mapping pixel value to radiance) is a polynomial for each color channel.
- **Iterate Degrees:** Test several polynomial degrees (e.g., 3-6).
- **Iterative Optimization (per degree, per channel):**
 - **Estimate CRF Coefficients:** Solve a linear system based on sampled pixel values and current exposure ratio estimates (R_j).
 - **Estimate Exposure Ratios R_j :** Update R_j (ratio of exposure $j + 1$ to j) by averaging $g(Z_{p,q})/g(Z_{p,q+1})$ using the current CRF g .
 - **Repeat:** Continue until the CRF estimate converges.
- **Select Best:** Choose the polynomial degree with the lowest error.
- **Calculate Exposures:** Determine relative exposure factors for each image based on the final R_j values.

3. `create_hdr_image` (Merge LDRs into HDR)

- **Scale Colors:** Calculate and apply scaling factors to align R and B channels relative to G.
- **Weighted Average (per pixel):**
 - For each input image:
 - Use the estimated CRF g to convert the pixel value Z to relative radiance $I = g(Z)$.
 - Divide radiance I by the image's relative exposure factor.
 - Apply the color scaling factor.
 - Calculate a weight (higher for mid-range pixel values).
 - Compute the final HDR pixel value as the weighted average of these radiance estimates from all images.

Robertson Method

1. `sample_pixels` (Select Pixels)

- **Sample:** Randomly choose a fixed number (`num_samples`) of unique pixel locations (y, x) from all possible image coordinates.

2. `recover_response_curve` (Estimate CRF & Irradiance Iteratively)

- **Goal:** Find the Camera Response Function g (mapping pixel value Z to relative radiance) and the relative irradiance E_i for each sampled pixel i .
- **Initialization (per channel):**
 - Initialize g as a linear ramp (normalized so $g(128) = 1$).
 - Initialize E_i for all sampled pixels to 1.
- **Iterative Optimization:**
 - **Loop until convergence:**
 - **Update Irradiances E_i :** Keeping g fixed, update the irradiance E_i for each sampled pixel i using a weighted average based on the equation
$$E_i = \sum_j w(Z_{ij})g(Z_{ij})\Delta t_j / \sum_j w(Z_{ij})(\Delta t_j)^2.$$
 - **Update Response Curve $g(z)$:** Keeping the E_i fixed, update the value of $g(z)$ for each possible pixel value z (0-255) using a weighted average based on the equation
$$g(z) = \sum_{i,j \text{ where } Z_{ij}=z} w(Z_{ij})E_i\Delta t_j / \sum_{i,j \text{ where } Z_{ij}=z} w(Z_{ij}).$$
 - **Normalize g :** Rescale g so that $g(128) = 1$.
 - **Check Convergence:** Stop if the average change in E_i values between iterations is below a threshold.
 - **Convert to Log:** Take the logarithm of the final converged g to get the log response curve (similar toDebevec's output format).

3. `create_hdr_image` (Merge LDRs into HDR)

- Identical to the one used in the Debevec implementation.
- **Weighted Average in Log Domain (per pixel):**
 - For each input image:
 - Use the estimated log CRF g to get the log radiance value: $\log_{rad} = g(Z)$.
 - Subtract the known log exposure time: $\log_{rad} = g(Z) - \ln(\Delta t)$.
 - Calculate a weight w (using `weight_function`).
 - Compute the final log HDR pixel value as the weighted average of these `log_rad` values from all images.
- **Convert to Linear:** Apply `np.exp()` to the resulting log HDR image to get the final linear HDR radiance map.

2.3 Tone Mapping Algorithmsformation to work in log domain

Fast Bilateral Filtering

1. `fast_bilateral_filter_channel` (Core Filtering Logic)

- **Downsample:** Shrink the input image channel.
- **Process Intensity Segments:** For different intensity ranges (`num_segments`):
 - Calculate how similar downsampled pixels are to the segment's intensity (`sigma_r`).
 - Spatially blur (Gaussian `sigma_s`) these similarity weights.
 - Spatially blur the intensity values weighted by similarity.
 - Divide the blurred weighted intensities by the blurred weights.
- **Upsample & Combine:** Enlarge results for each segment and average them to get the final filtered channel.

2. `fast_bilateral_tonemap` (Tone Mapping Workflow)

- **Isolate Luminance:** Convert HDR image to HSV (if color) to work on the Value (brightness) channel.
- **Filter Luminance:** Apply `fast_bilateral_filter_channel` to the Value channel using spatial (`sigma_s`) and range (`sigma_r`) parameters.
- **Recombine Color:** Convert back to RGB (if color).
- **Compress & Display:** Apply log scaling, gamma correction, normalize to [0,1], and convert to 8-bit LDR.

Drago & Mantiuk & Reinhard Tone Mapping

Implemented directly using opencv.